SNAP ORBIT DESIGN

VASSILIS ANGELOPOULOS, DAVID PANKOW, MIKE LAMPTON

SPACE SCIENCES LAB, UC BERKELEY

MICHAEL LEVI

LAWRENCE BERKELEY NATIONAL LABORATORY

REQUIREMENTS

Total Dose ~< 100 kRads mission total, through ~3mm of Al (for electronics)

Dose Rate During Observations< 1rad/year

Notes:
- 1 rad=60TeV/gram
- dE/dX=2MeV cm^2 / gram
- particles/cm^2 = $3 \cdot 10^7$ * rads
- rads ~ $3 \cdot 10^{-8}$ * particles/cm^2
- For typical GigaCam pixel size 0.01cm x 0.03cm
- Each rad produces 10^4 hits
- For 0.1 hits/exposure (10% error) need 10^{-5} rads/exposure
- For 300 sec exposures, need $3 \cdot 10^{-8}$ rad/sec = 1rad/year

Total Non-Ionizing Energy Loss < 1rad or $3 \cdot 10^7$ particles/cm^2 mission total

Note: Applies to proton dose through reasonable shielding.
Similar to dose rate, but refers to permanent damage.

Average IR Earthglow input < 1W/m^2

Must be << Sunlight absorption = 14W/m^2

Slew Rate for GigaCam must be reasonable ~ 1degree/second

Sun avoidance > 70deg away from look direction

Earth, Moon avoidance > 45deg away from look direction

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INCLINED ORBITS	Total Dose, Solar Min (in 12mm 4pi str Al sphere) [Rads Yearly]	Fraction of time w/ DoseRate <1Rad/yr 12mm 4pi Al sphere [% observ. time]	Average Input IR Earthglow [W/m^2]	South Pole Data?
LEO (600km alt, sun-synch)	100.	76% (1)	70.	50%
Molnyia (Prg=279km alt., Apg=6.3Re alt., Inc=63.4deg, T=12hrs, APer=90deg.)	2000.	65%	6.	Limited
Extended Molnyia (Prg=1500km alt., Apg=11.Re alt., Inc=63.4deg, T=24hrs, Aper=0).	100.	70%	2.5	50%
Extended Northern Pole Molnyia (PrgXApg=3X8.2Re Alt., Inc=63.4deg, T=24hrs, Aper=90).	200.	75%	1.5	Limited
1X10.2 Re (PrgXApg Alt., Inc=90. deg T=24hrs, Aper=0).	100.	67%	1.8	Unli-mited

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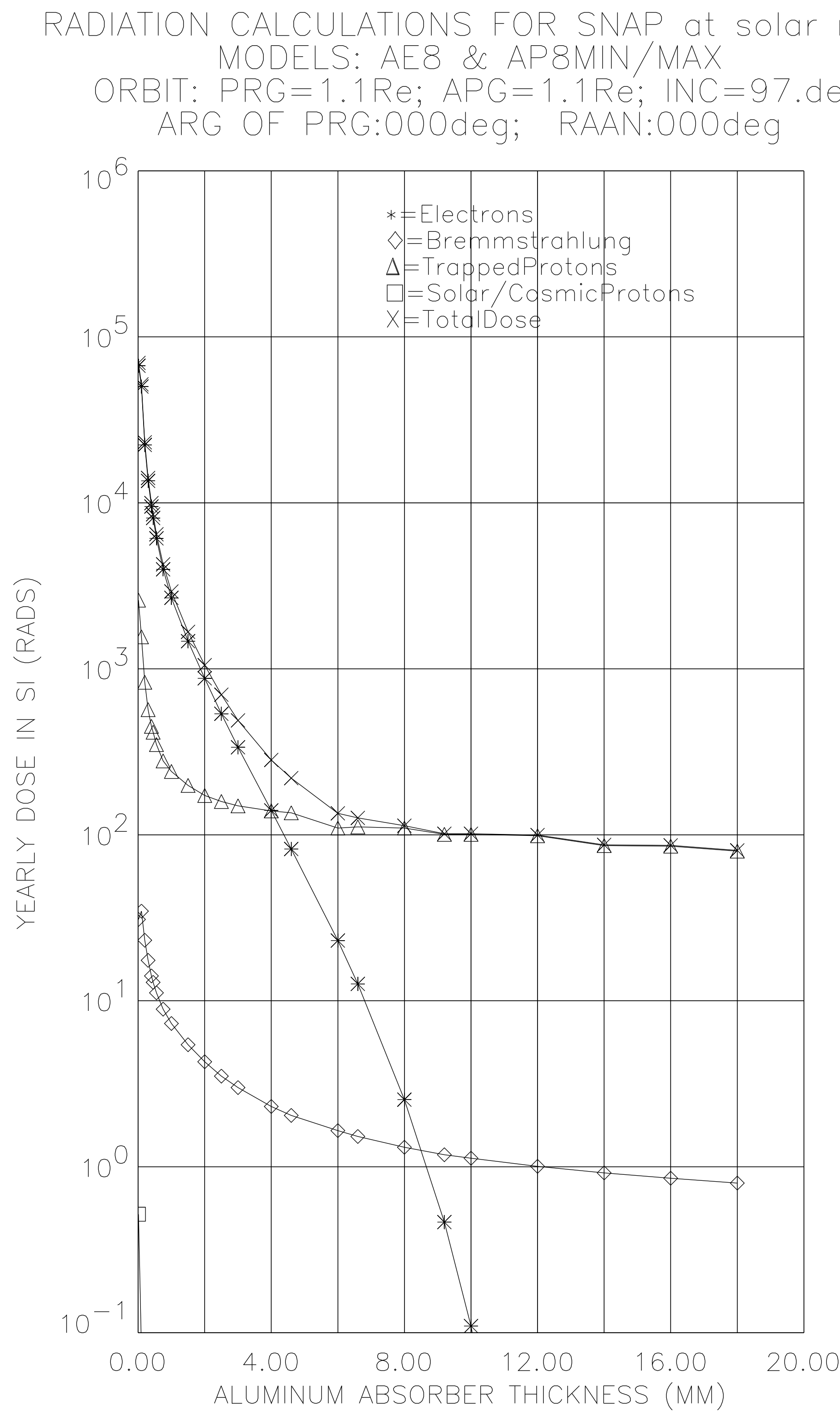
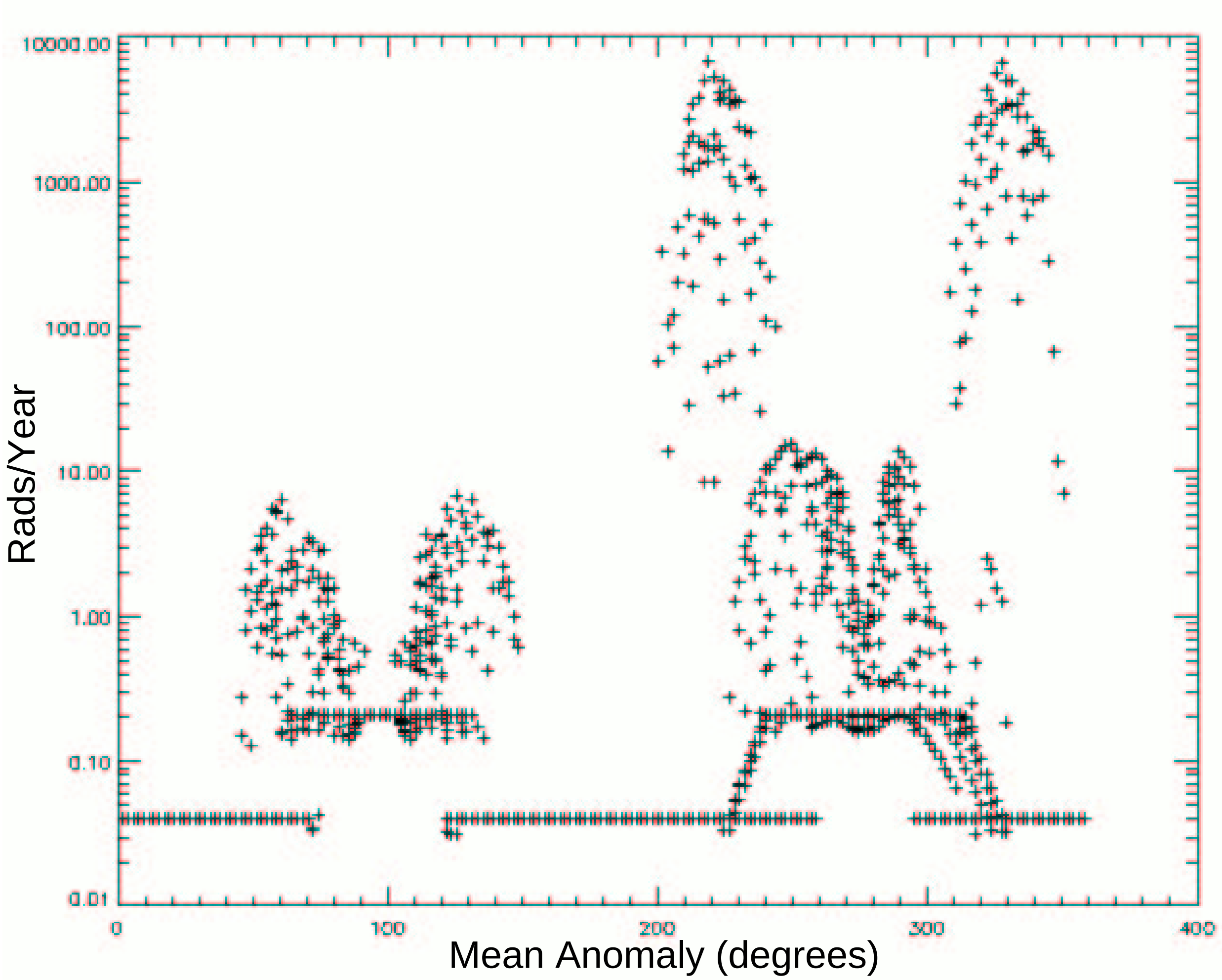
NEAR EQUATORIAL HEO ORBITS (Inc<30, A>6.Re)				
2.56789X24.9132 Re (PrgXApg geocentric, T=72hrs).	60.	86%	.5	Unli-mited
2X19.2 Re (PrgXApg geocentric, T=48hrs).	200.	84%	.8	Unli-mited
3X18.2 Re (PrgXApg geocentric, T=48hrs).	150.	80%	.7	Unli-mited
VERY HIGH ALTITUDE ORBITS				
Prometheus Short (8X40 Re, PrgXApg, geocentric, Inc=00)	0.8	94%	.04	Unli-mited
Prometheus Long (19X57 Re, PrgXApg, geocentric, Inc=00)	0.3	100%	.01	Unli-mited

(1) 6% loss from typical poleward expansion of auroral oval at active times by 5degrees.
(2) Assumes 4m^2 radiator looking at Earth as worst case scenario

Example of Dose-Depth curve for LEO orbit:



Example of Dose Rate (Rads/Year) versus mean anomaly (i.e., time in orbit normalized to orbital period, in units of degrees going from 0-360).

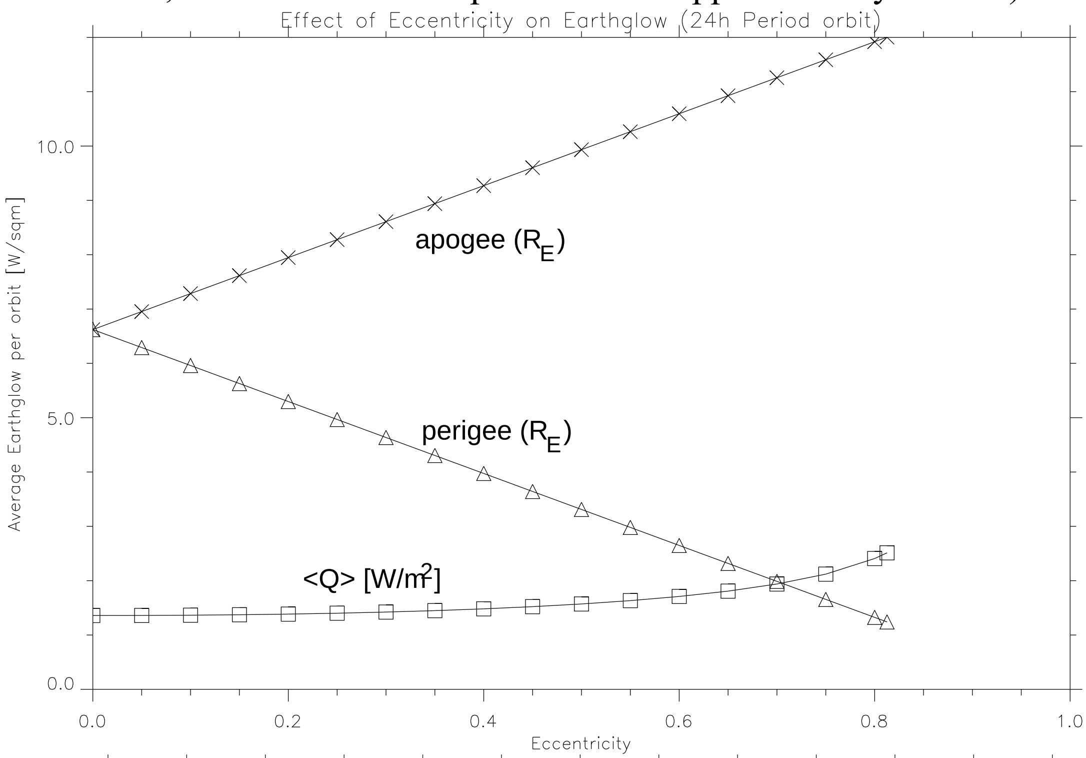


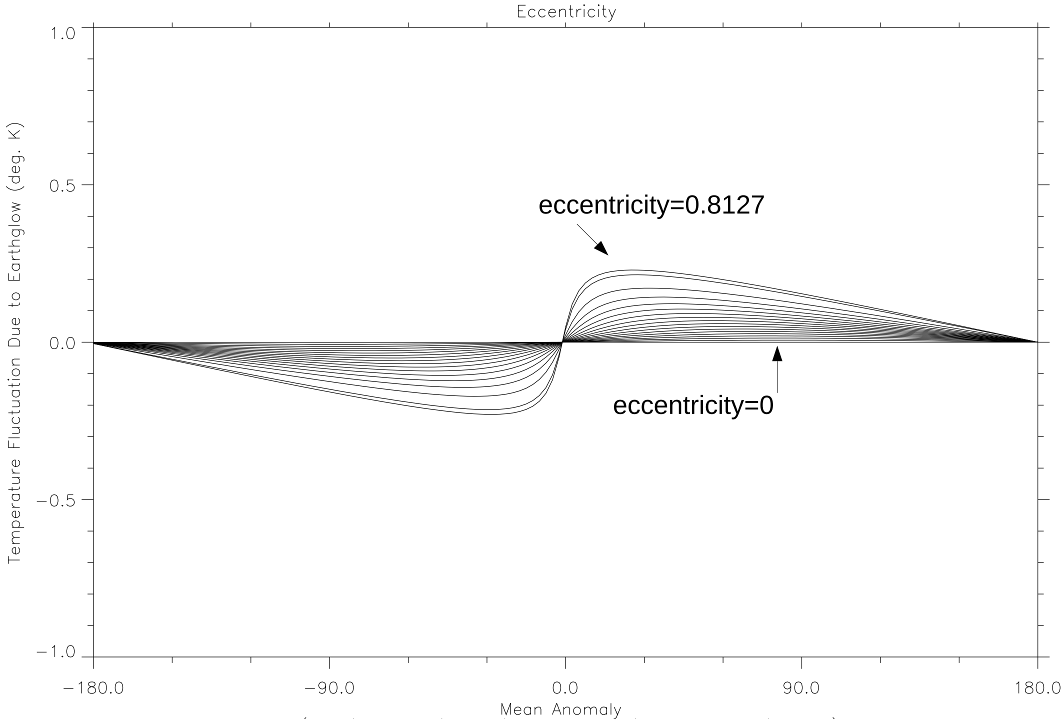
Example of thermal radiation computation. How does Earthglow (Q_0 = 237 W/m^2 in IR) affect s/c temperature on average and as a function of location in orbit.

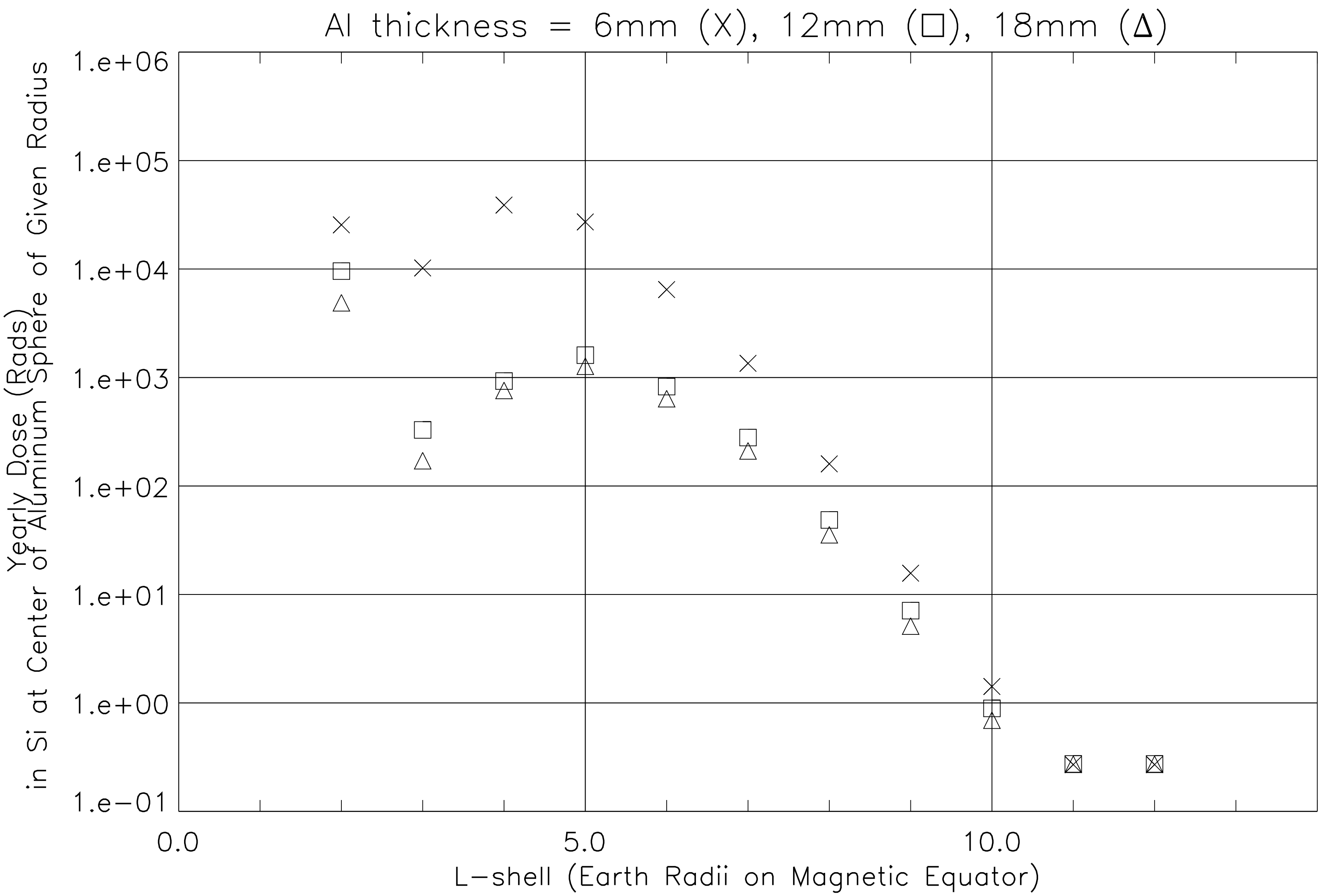
1) Al spacecraft (single node) of 1275 kg mass, and specific heat 900. J/kg/K.

2) Use equation (Pankow) of heat at a distance: $Q(R)=0.5 * Q_0 * (1-\mathrm{sqrt}(1-(R_E/R)^2)$

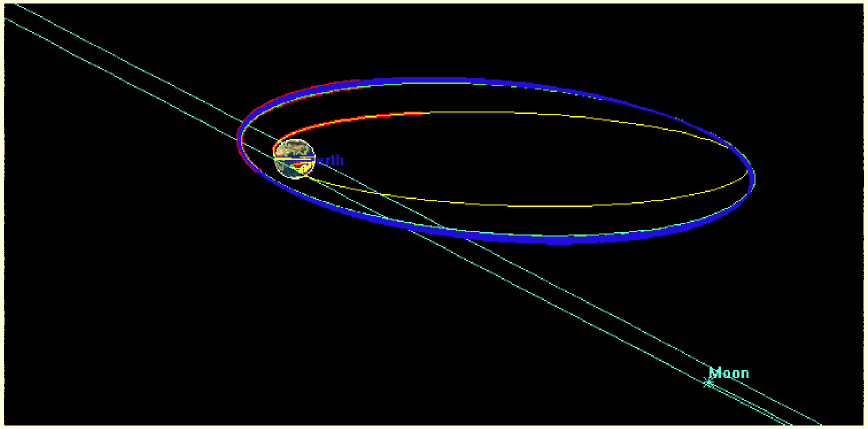
3) Need orbit average to be ~1W/m^2 because the radiator plate can only dissipate a few (~4-5 W/m^2, while internal heat production is approximately 4W/m^2).



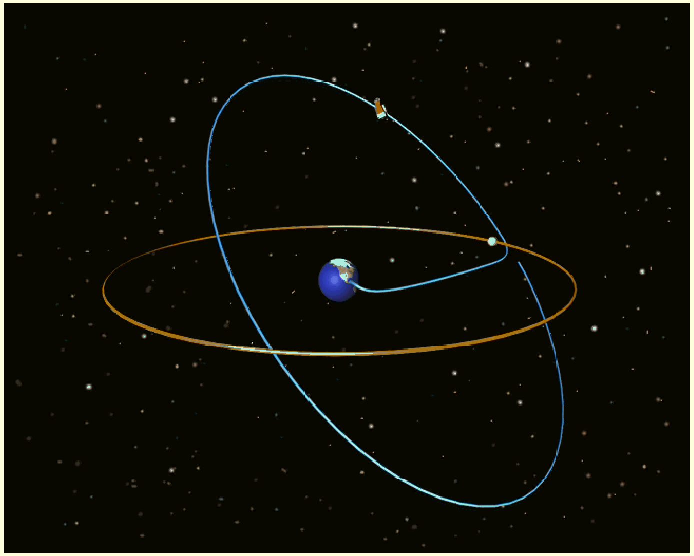



Al thickness = 6mm (X), 12mm (□), 18mm (Δ)
Yearly Dose (Rads)
in Si at Center of Aluminum Sphere of Given Radius
1.e+06
1.e+05
1.e+04
1.e+03
1.e+02
1.e+01
1.e+00
1.e−01
0.0
5.0
10.0
L−shell (Earth Radii on Magnetic Equator)

- **High and Very High Earth Orbits**
- **Good Overall Optimization of Mission Trade-offs**
- **Low Earthglow and Albedo Provide Multiple Advantages:**
  - —**Minimum Thermal Change on Structure Reduces Demand on Attitude Control**
  - —**Excellent Coverage from Berkeley Groundstation**
  - —**Outside Outer Radiation Belt (elliptical 3 day - 84% of orbit)**
  - —**Passive Cooling of Detectors**
  - —**Minimizes Stray Light**



Chandra type highly elliptical orbit



Lunar Assist orbit

Prometheus Orbit:

1) 19 x 57 Re high inclination, but inclination and apogee/perigee time variable. Orbit sensitive to launch time. **

2) Required ~200 kg propulsion to attain orbit – orbit disposal unknown

3) Long Eclipses (5.5 hrs) **

4) Requires 4 ground stations, 50 Mbit/s continuous, 25 W spacecraft transmitter **

5) Requires gimballed antenna **

6) Poor southern hemisphere observing **

7) Excellent lift capacity to orbit

8) No thermal snap issues

Elliptical Orbit:

1) 2 x 24.5 Re low inclination, very stable orbit insensitive to launch time.

2) Requires less propellant to attain orbit and dispose satellite after mission.

3) Shorter Eclipses (ave. 1 hr, longest 2 hr, but more frequent)

4) Requires 1 ground station, 200 Mbit/s, 5 W spacecraft transmitter in single 5 hr. dump

5) Body mounted antennae

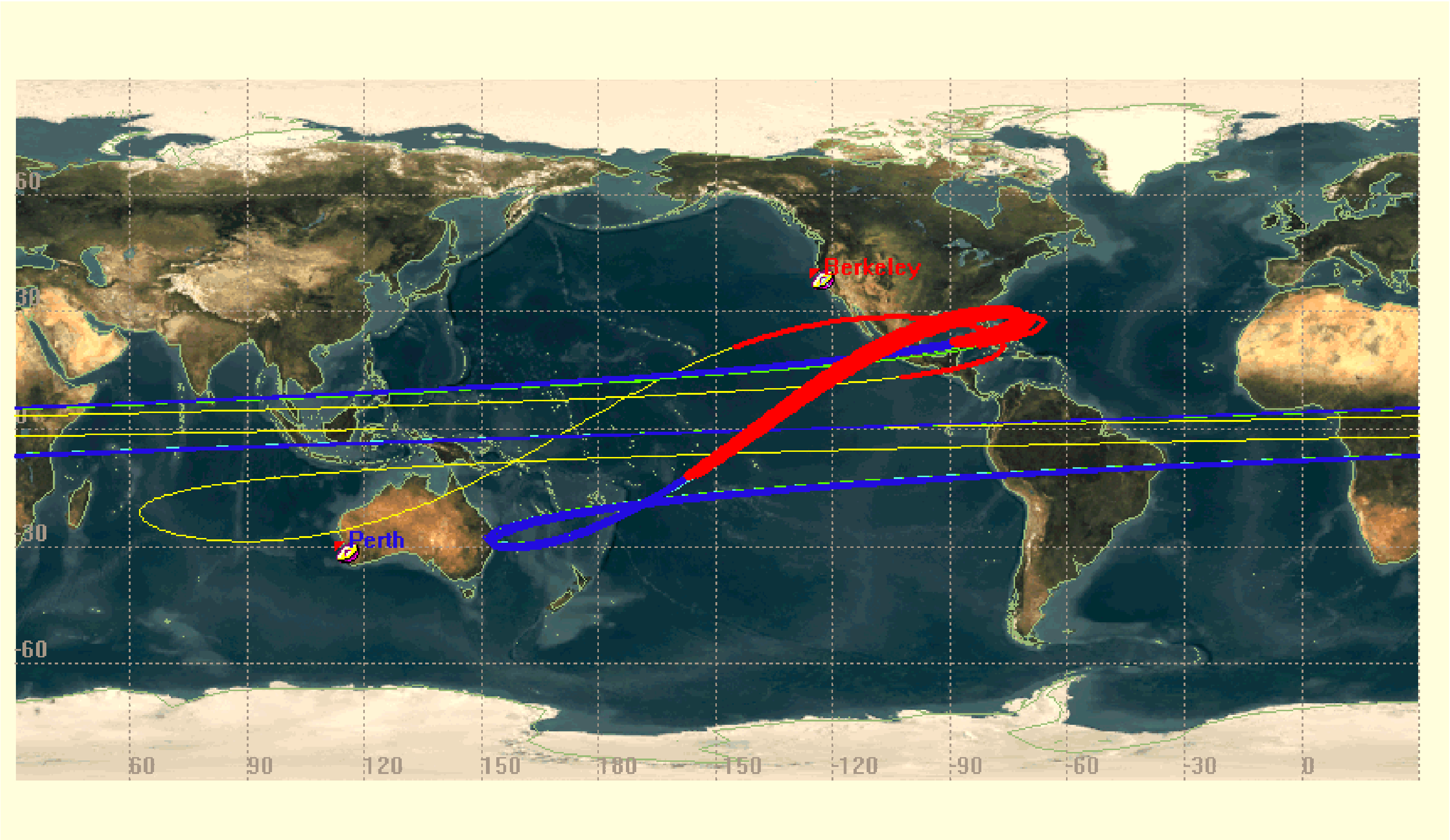
6) Good northern & southern hemisphere observing

7) Excellent lift capacity to orbit

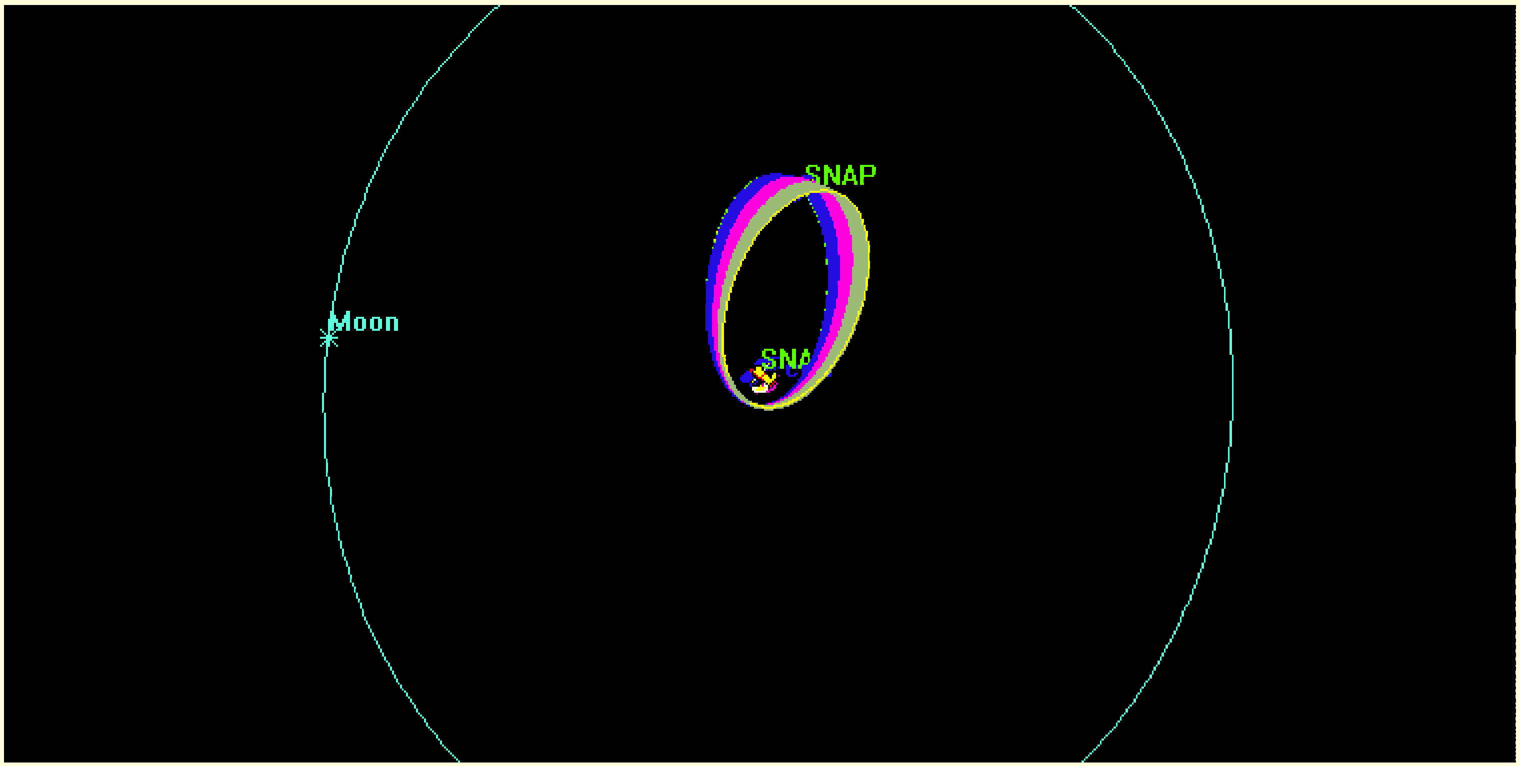
8) Thermal snap at earth pass **

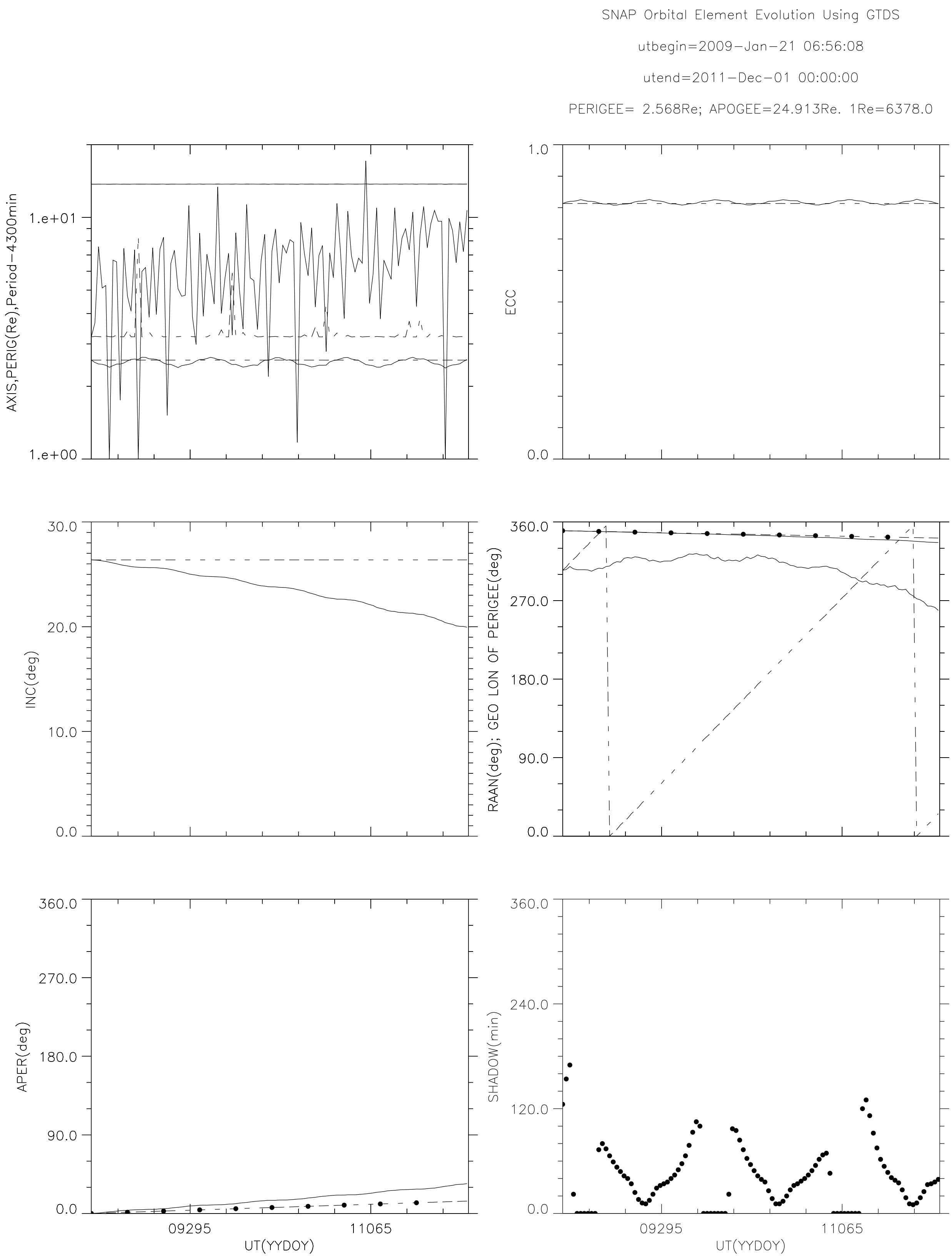
NIEL radiation analysis for trapped protons after 25 mm Al shielding.

Rp [km]	Ra [km]	Frac orbit below 60,000km		trapped p/cm^2/year 25 mm Al
12,000	150,930	0.161		0.0e0 trapped p/cm^2 25mm Al
10,000	152,830	0.156		8.2e5 trapped p/cm^2 25mm Al
8,000	154,830	0.151		1.2e7 trapped p/cm^2 25mm Al
7,000	155,830	0.149		4.7e7 trapped p/cm^2 25mm Al
6,000	156,830	0.146		1.6e8 trapped p/cm^2 25mm Al



Berkeley
Perth
60
30
0
-30
-60
60
90
120
150
180
-150
-120
-90
-60
-30
0


SNAP
Moon
SNA


SNAP Orbital Element Evolution Using GTDS
utbegin=2009-Jan-21 06:56:08
utend=2011-Dec-01 00:00:00
PERIGEE= 2.568Re; APOGEE=24.913Re. 1Re=6378.0
AXIS,PERIG(Re),Period-4300min
1.e+01
1.e+00
ECC
1.0
0.0
INC(deg)
30.0
20.0
10.0
0.0
RAAN(deg); GEO LON OF PERIGEE(deg)
360.0
270.0
180.0
90.0
0.0
APER(deg)
360.0
270.0
180.0
90.0
0.0
SHADOW(min)
360.0
240.0
120.0
0.0
09295
11065
UT(YYDOY)
09295
11065
UT(YYDOY)

By matching the lunar orbital elements we achieve:

1) Relative stability of inclination, perigee (and period) to lunar perturbations.

2) Inclination remains within 10deg of launch inclination throughout mission. Both moon and Earth are > 55degrees from ecliptic north and south.

By choosing the mean anomaly at launch and fine-tuning the period we achieve:
Stable perigee geo-longitude (within 30 degrees of launch) throughout mission.
Routine contact opportunities with Berkeley do not require stationkeeping.

Access times from Berkeley are good:
1) Average access time = 5.4 hours
2) Shortest access time = 5.2 hours
3) Contacts happen when we are inside radiation belts and not observing.

Satellite easy to dispose of gracefully upon mission termination:
Raise apogee (to 40 R_E) and wait for it to re-enter within 2000 days.
Continue observations at lower priority on an as needed basis.

	PrgAlt, km	ApgAlt, km	PrgDist, Re	ApgDist, Re	axis	ellipticity	Launch Mass, kg	Max dry mass, kg	Max fuel, kg
DIV 4040-12:	185	152830	1.029	24.962	12.996	0.921	3011	2405	456
DIV 4040-12:	2000	152830	1.314	24.962	13.138	0.900	2220	1821	288
DIV 4040-12:	5000	152830	1.784	24.962	13.373	0.867	1550	1320	152
DIV 4240-12:	7000	152830	2.098	24.962	13.530	0.845	2330	2028	185
DIV 4450-14:	10000	152830	2.568	24.962	13.765	0.813	2230	1999	119

								Final mass, kg	Fuel, kg
Re(km)=	6378	**Max. mass to Initial Orbit (Launch vehicle lift capacity)=**						3011	0
					Fixtures (clampbands, etc)=			151	0
		Ra	Rp	Va	Vp	dV(km/s)	Isp (s)		
Initial Placement:		24.96	1.029	0.445	10.793			2860	0
Prg raise to 10000.		24.96	2.568	0.683	6.639	0.238	210	2548	312
Apg raise to 40Re:		40	2.568	0.434	6.758	0.120	210	2405	456
Total (maximum):						0.358		2405	456

Summary

Epoch:	Feb 28, 2009 00:30:00
Perigee:	10,015 km altitude (2.57 R_E geocentric)
Apogee:	159,046km altitude (24.94 R_E geocentric)
Eccentricity:	0.813116
Inclination:	26.3733 degrees
Period:	3 days (258496 seconds)
RAAN:	349.938 degrees
APER:	0 degrees
True anomaly:	0 degrees

New orbit is a winner for many reasons.

Stable

Short eclipses

Low Earthglow and albedo thermal effects and long-period thermal cycling

Slew GigaCam according to science not thermal considerations

Satisfies environmental radiation requirements

Long observation time

When not observing half of the time spent transmitting data

No stationkeeping required for good contacts

No special ACS maneuvers required to keep Sun/Earth/Moon outside FOV

Easy to get to and gracefully terminate mission with the cheapest DeltaIV.